Flip angle calibration for high resolution mapping of the long range diffusion coefficient by hyperpolarized 3He MRI

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Introduction: In recent years hyperpolarized helium-3 magnetic resonance imaging (HP ^{3}He MRI) shows promise as an ideal imaging tool for quantitative assessments of pulmonary parameters. This technique can provide lung structure information at both microscopic and macroscopic levels. The apparent diffusion coefficient (ADC), which measures the diffusivity of ^{3}He atoms inside the alveoli, characterizes the lung's microstructure at the alveolar level. The long range diffusion coefficient (long D) measures the ^{3}He long length scale diffusion between lung airways at the macroscopic level. The abnormality in long D value is relevant to diseases affecting airway structure. In the current method, in which the long range diffusion coefficient was measured by a spatial Fourier transform associated with a sliding window, the spatial resolution is limited [1]. In this work, we present a method for obtaining a high resolution mapping of the long range diffusion coefficient in the lung.

Method: In the HP ^{3}He MRI long range diffusion coefficient measurement, the initial longitudinal magnetization is modulated for the purpose of spin tagging. The temporal signal evolution can be expressed as $M(t) = M_0 \cdot \exp(-t/T_1) \cdot \left[\cos^2\theta - \sin^2\theta \cdot \cos(kx) \cdot \exp(-R \cdot t)\right]$, where M_0 is the initial magnetization, T_1 is the polarization relaxation rate, θ is the tagging flip angle, k is the tagging wave number, $R = D_{long} \cdot k^2$ is the tagging decay rate, and D_{long} is the long range diffusion coefficient. In the time scale of the long D measurement, the depolarization caused by RF pulses is the major factor contributing to T_1. Thus the acquired signal intensities of a series of images are: $S_n = S_0 \cdot \exp(Nn \ln(\cos\alpha)) \cdot \left[\cos^2\theta - \sin^2\theta \cdot \cos(kx) \cdot \exp(-R \cdot n \cdot \Delta\tau)\right]$, where S_0 and S_n are the signal intensity of the first image and the n^{th} image, α is the flip angle and Δτ is the inter-scan time between two images. It is difficult to retrieve R from a series of measured images, since S_n is a complicated function of the unknowns α, θ and R. However, if the flip angle α is calibrated, the problem is converted into a simple exponential fitting problem: $E_n = S_n / \left(S_0 \cdot \exp(Nn \ln(\cos\alpha))\right) = \left[a_1 - a_2 \cdot \exp(-R \cdot \Delta\tau \cdot n)\right]$, in which a_1, a_2 and R are unknowns. Thus a high resolution mapping of long D values can be obtained from the pixel-by-pixel fitting procedure.

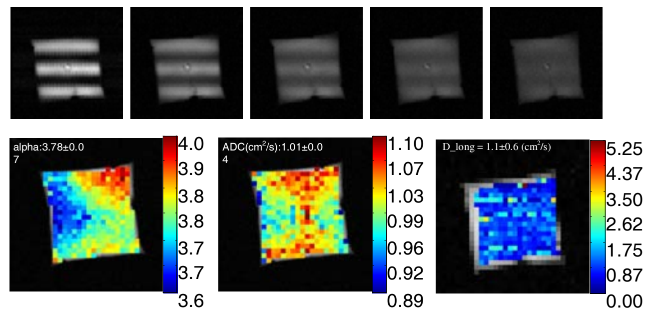

Fig.1. long range diffusion coefficient and apparent diffusion coefficient measured on a free-diffusion phantom experiment. The first row is the longitudinal spin tagging images.

Result and Discussion: To validate the method described above we performed both phantom and animal experiments. Hyperpolarized (HP) ^{3}He gas was prepared in a prototype polarizer (Amersham Health, Durham, NC). A 2D gradient echo (GRE) sequence with a longitudinal spin tagging preparation was used for imaging. The tagging preparation is implemented by sandwiching a gradient between two RF pulses. The gradient amplitude G is proportional to the tagging wave number: $G = k/(\gamma \cdot t)$, where γ is the ^{3}He gyromagnetic ratio and t=500us is the gradient duration. In the phantom experiment, a plastic bag filled with 100ml ^{3}He and 200ml nitrogen was imaged in a 1.5T scanner (Siemens Sonata). The basic assumption is that the ADC value should be equal to the long D value in a free diffusion environment. The ADC was measured first; a flip angle map can be calculated from the ADC by using the multiple regression method described in ref[2]. In the tagging measurement, 5 images were acquired back-to-back with the key scan parameters: tagging wavelength: 40mm; FOV:300mm; slice thickness:100mm; TR/TE:10/6.26ms; and base resolution: 64x64. The data was fitted pixel-by-pixel to obtain the long D map. As shown in fig. 1, the measured long D value agrees with the ADC value. The animal experiment was conducted under an IACUC approved protocol. A New Zealand rabbit was sedated with ketamine and ventilated with a home-built ventilator. A tidal volume of 25ml HP ^{3}He gas was administered to the rabbit after two ^{3}He pre-washes. Six tagging images were acquired with the scan parameters: tagging wavelength 10mm; FOV: 140mm; slice thickness: 15mm; TR/TE:7.1s/2.8s; basic resolution: 64x64; inter-scan time Δτ=1.36s. As in the phantom experiment, a flip angle map was obtained from the ADC measurement. Figure 2 shows maps and histograms of α, ADC and long D values in the rabbit lung. We notice that the long range diffusion coefficient is smaller than the apparent diffusion coefficient by a factor of 0.17/0.006≈28.

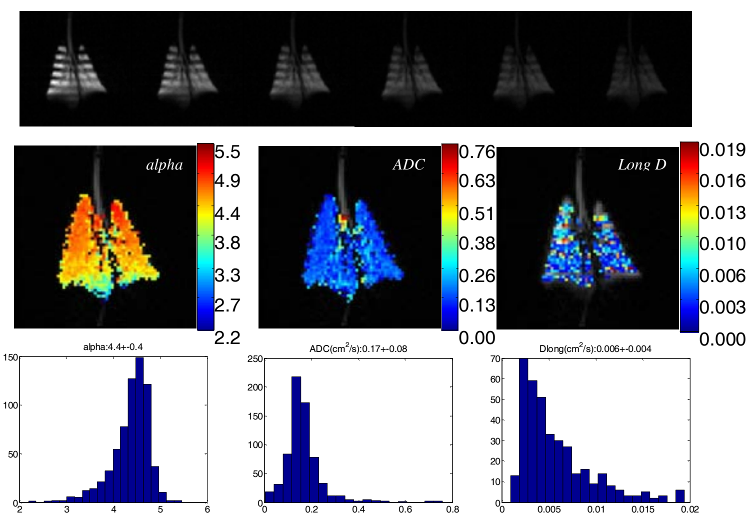

Fig.2. long range diffusion coefficient and apparent diffusion coefficient measured in the rabbit experiment. The first row is the longitudinal spin tagging images. The statistical values (average ± standard deviation) are listed above the corresponding histograms

Conclusion: In this work we show that with flip angle calibration a high resolution mapping of long range diffusion coefficient can be achieved. We demonstrate the validity of this method in phantom and animal models.

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References: 1 Woods JC, *et al.*, *Magn Reson Med* 2004;51:1002-1008. 2.) J. Yu, *et al.*, J. *Magn Reson Imag* (accepted)